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**U.S. PATENT APPLICATION**

**FOR**

**TRAILING EDGE TAPER DESIGN AND METHOD FOR MAKING A**

**PERPENDICULAR HEAD WITH SHIELDING**

**INVENTORS:**  
**James Nix**  
**Jui-Lung Li**  
**Quang Le**  
**Neil Robertson**  
**Ian McFadyen**  
**Yimin Hsu**  
**Mason Williams**

**ASSIGNEE:     HITACHI GLOBAL STORAGE TECHNOLOGIES**

**SILICON VALLEY IP GROUP, PC**  
**P.O. BOX 721120**  
**SAN JOSE, CA 95172**

# **TRAILING EDGE TAPER DESIGN AND METHOD FOR MAKING A PERPENDICULAR WRITE HEAD WITH SHIELDING**

## **FIELD OF THE INVENTION**

5           The present invention relates to perpendicular magnetic recording, and more particularly to a trailing shield design using a trailing shield taper for improved magnetic field strength and field gradient performance.

## **BACKGROUND OF THE INVENTION**

10           At the heart of a computer is a magnetic disk drive that includes a magnetic disk, a slider where a magnetic head assembly including write and read heads is mounted, a suspension arm, and an actuator arm. When the magnetic disk rotates, air adjacent to the disk surface moves with it. This allows the slider to fly on an extremely thin cushion of  
15           air, generally referred to as an air bearing. When the slider flies on the air bearing, the actuator arm swings the suspension arm to place the magnetic head assembly over selected circular tracks on the rotating magnetic disk, where signal fields are written and read by the write and read heads, respectively. The write and read heads are connected to  
20           processing circuitry that operates according to a computer program to implement write and read functions.

          Typically magnetic disk drives have been longitudinal magnetic recording systems, wherein magnetic data is recorded as magnetic transitions formed longitudinally

on a disk surface. The surface of the disk is magnetized in a direction along a track of data and then switched to the opposite direction, both directions being parallel with the surface of the disk and parallel with the direction of the data track.

5 Data density requirements are fast approaching the physical limits, however. For example, increases data capacity requires decreased bit sizes, which in turn requires decreasing the grain size of the magnetic medium. As this grain size shrinks, the magnetic field required to write a bit of data increases proportionally. The ability to produce a magnetic field strong enough to write a bit of data using conventional longitudinal write head technologies is reaching its physical limit.

10 One means for overcoming this physical limit has been to introduce perpendicular recording. In a perpendicular recording system, bits of data are recorded magnetically perpendicular to the plane of the surface of the disk. The magnetic disk may have a relatively high coercivity material at its surface and a relatively low coercivity material just beneath the surface. A write pole having a small cross section and very high flux  
15 emits a strong, concentrated magnetic field perpendicular to the surface of the disk. This magnetic field emitted from the write pole is sufficiently strong to overcome the high coercivity of the surface material and magnetize it in a direction perpendicular to its surface. This flux then flows through the relatively magnetically soft underlayer and returns to the surface of the disk at a location adjacent a return pole of the write element.  
20 The return pole of the write element has a cross section that is much larger than that of the write pole so that the flux through the disk at the location of the return pole (as well as the resulting magnetic field between the disk and return pole) is sufficiently spread out

to render the flux too weak to overcome the coercivity of the disk surface material. In this way, the magnetization imparted by the write pole is not erased by the return pole.

It will be appreciated by those skilled in the art that the high coercivity of the disk surface material can make it difficult to magnetize, especially at increasingly small magnetic grain sizes. It has been found that angling the magnetic field slightly can improve transition sharpness and achieve better media signal to noise ratio. A proposal to achieve this has been to place a trailing shield near the write gap and magnetically connected with the return pole. The shield would in effect attract field emitted from the write pole, thereby angling it slightly.

A challenge encountered with this approach is that some field is lost to the shield, and increasing write field to compensate for this can lead to adjacent track interference due to stray fields. In other words, using a trailing shield to angle the magnetic field emitted from the write pole advantageously decreases the switching field necessary to make the perpendicular magnetic transition, increasing the speed with which data can be written. However, this improvement in switching field comes at the cost of lost magnetic field. This is because some of the field leaks to the shield (in a direction parallel to the disk surface) resulting in a weaker field being emitted by the write pole. Therefore, there remains a strong felt need for a mechanism for canting the magnetic field of a perpendicular write pole, while minimizing field loss. In addition, a mechanism for doing so would have to be manufacturable in a mass production setting to be practicable.

## SUMMARY OF THE INVENTION

The present invention provides a magnetic write head for perpendicular recording that  
5 provides improved write field and write gradient performance. The write head includes a  
write pole and a trailing shield having a tapered surface. A return pole stitched to the trailing  
shield is magnetically connected with the write pole at a location away from the ABS  
surface.

The tapered surface of the trailing shield can be parallel to an adjacent tapered surface  
10 of the write pole. The use of a trailing shield in a perpendicular magnetic write head  
improves write performance, but also leads to lost field leaking from the write head to the  
shield through the write gap, which can result in reduced write field strength. The tapered  
surface of the trailing shield alleviates this lost field while retaining the advantage of having  
a trailing shield present. By tapering a surface of the shield, and preferably adjacent portion  
15 of the write pole, any field leaking to the sensor will be canted in a direction toward the ABS.  
A component of this field vector is in a desired direction perpendicular to the ABS (toward  
the magnetic medium) and therefore contributes to field strength. Experiments have shown  
substantial write performance through the use of such a tapered shield.

In order to avoid side writing, which might otherwise contribute to adjacent track  
20 interference, the tapered trailing shield can include laterally flared wing portions as well as a  
taper. These laterally flared wing portions could initiate at a point closer to the ABS than the  
point of taper initiation.

## **BRIEF DESCRIPTION OF THE DRAWINGS**

For a fuller understanding of the nature and advantages of this invention, as well as the preferred mode of use, reference should be made to the following detailed description  
5 read in conjunction with the accompanying drawings.

FIG. 1 is a schematic view of a magnetic storage system in which the present invention might be embodied;

FIG. 2 is a cross sectional view of a perpendicular magnetic write head according  
10 to an embodiment of the present invention;

FIG. 3 is a plan view, taken from line 3-3 of FIG. 2, illustrating a write pole for use in the embodiment illustrated in FIG. 2;

FIG. 4 is an ABS view, taken from line 4-4 of FIG. 2, of the embodiment illustrated in FIG. 2;

15 FIGS. 5-8 are cross sectional views of a portion of a magnetic write element in intermediate stages of manufacture;

FIG. 9 is perspective view of a tapered shield according to an embodiment of the invention; and

FIG. 10 is a side view of the tapered shield illustrated in FIG. 9.

### **BEST MODE FOR CARRYING OUT THE INVENTION**

The following description is the best embodiment presently contemplated for carrying out this invention. This description is made for the purpose of illustrating the general principles of this invention and is not meant to limit the inventive concepts claimed herein.

Referring now to FIG. 1, there is shown a disk drive 100 embodying this invention. As shown in FIG. 1, at least one rotatable magnetic disk 112 is supported on a spindle 114 and rotated by a disk drive motor 118. The magnetic recording on each disk is in the form of an annular pattern of concentric data tracks (not shown) on the magnetic disk 112.

At least one slider 113 is positioned near the magnetic disk 112, each slider 113 supporting one or more magnetic head assemblies 121. As the magnetic disk rotates, the slider 113 is moved radially in and out over the disk surface 122 so that the magnetic head assembly 121 may access different tracks of the magnetic disk where desired data are written. Each slider 113 is attached to an actuator arm 119 by way of a suspension 115. The suspension 115 provides a slight spring force which biases slider 113 against the disk surface 122. Each actuator arm 119 is attached to an actuator means 127. The actuator means 127 as shown in FIG. 1 may be a voice coil motor (VCM). The VCM comprises a coil movable within a fixed magnetic field, the direction and speed of the coil movements being controlled by the motor current signals supplied by controller 129.

During operation of the disk storage system, the rotation of the magnetic disk **112** generates an air bearing between the slider **113** and the disk surface **122** which exerts an upward force or lift on the slider. The air bearing thus counter-balances the slight spring force of suspension **115** and supports the slider **113** off and slightly above the disk surface by a small, substantially constant spacing during normal operation.

The various components of the disk storage system are controlled in operation by control signals generated by control unit **129**, such as access control signals and internal clock signals. Typically, the control unit **129** comprises logic control circuits, storage means and a microprocessor. The control unit **129** generates control signals to control various system operations such as drive motor control signals on line **123** and head position and seek control signals on line **128**. The control signals on line **128** provide the desired current profiles to optimally move and position slider **113** to the desired data track on disk **112**. Write and read signals are communicated to and from write and read heads **121** by way of recording channel **125**.

The above description of a typical magnetic disk storage system, and the accompanying illustration of FIG. **1** are for representation purposes only. It should be apparent that disk storage systems may contain a large number of disks and actuators, and each actuator may support a number of sliders.

With reference to Fig. **2**, the present invention provides a write head **200**, for use in perpendicular recording that has a trailing shield **202** incorporating a tapered surface **204** for improved magnetic performance. The write head is built upon a dielectric layer **206**, that can be for example alumina  $\text{Al}_2\text{O}_3$  or some other non-magnetic material. The



dielectric layer **206** is generally formed on top of a read element (not shown) and separated the write head **200** there from.

A magnetic shaping layer **208** is formed over the substrate **206** and has an end **210** that is recessed from an air bearing surface (ABS) **212**. A non-magnetic, dielectric material **214** fills the space between the end **210** of the shaping layer **208** and the ABS **212**. The shaping layer **208**, and fill material **214**, preferably have coplanar upper surfaces which can be produced by a chemical mechanical polishing process.

With continued reference to Fig. 2 a write pole **216** is formed over the shaping layer and has a pole tip **218**, which extends to the ABS surface **212**. Whereas the write pole extends straight back from the ABS in the pole tip region **218** for short distance, at a flare point indicated by line **220**, the write pole begins to flare laterally outward, which can be seen more readily with reference to Fig. 3. With reference to Fig. 2, the write pole has a tapered portion **222**, which may initiate at a point **224**, which may occur before the flare point **220** of the write pole **216**, or could occur after the flare point **220** (ie. further from the ABS) depending upon design requirements.

A thin non-magnetic write gap layer **226** is formed over the write pole. The write gap layer **226**, can be formed of many non-magnetic materials, such as alumina  $\text{Al}_2\text{O}_3$ , and in is preferably formed of a layer of alumina and a layer of diamond like carbon, for reasons that will be discussed below.

The tapered trailing shield **202** is formed over the write gap layer **226** in the pole tip region **218** of the write element **200**. The trailing shield assumes shape of the write pole **216** over which it is formed, having a tapered shape **204** at its bottom that

corresponds with the taper **222** of the write pole **216**. In this sense the taper begins at essentially the same distance **224** from the ABS **212**.

A magnetic return pole **230** is stitched to the top of the trailing shield **202** and extends back to a back gap region **232**, where it magnetically connects with the write pole **208** forming a magnetic yoke **234** therewith. The writer **200** also includes an electrically conductive coil **236**, having a plurality of winds **238** (shown in cross section), which pass through the magnetic yoke **234**. A non-magnetic, dielectric layer **240** surrounds and insulates the winds **238** of the coil **236**.

The presence of the magnetic shield **202** improves the field gradient and improves switching field performance by advantageously canting the write field emitted from the write pole **216**. However, previously the presence of a trailing shield has meant a loss of write field. Prior art designs have used trailing shields and write poles adjacent thereto that extend straight back from the ABS with no taper. In other words, the surfaces of the trailing shield and write pole in contact with the write gap were extended perpendicular to the ABS. Field lost between the write pole and shield using such a design could be described as a vector oriented parallel with the ABS and perpendicular to the primarily desired direction of emitted write field. Therefore, no component of this vector of lost field contributes to write field. By providing a taper **228** on the trailing shield, field leaking between the write pole and the trailing shield is angled toward the magnetic medium. A component of this vector then contributes to write field and improves write field strength. Experimentation has shown significant improvement in write field performance through the use of such a tapered trailing shield **202**. The tapered surface portion of the trailing shield **202** defines a plane having an angle of preferably less than

90 degrees with respect to the ABS and more preferably an angle of between 60 and 90 degrees with respect to the ABS.

Figs. 5-8 illustrate a process for constructing such a tapered trailing shield perpendicular write head 200. With reference to Fig. 5, a shaping layer 502 and an adjacent layer of non-magnetic material 504 such as alumina are formed on a substrate (not shown). These can be formed by processes familiar to those skilled in the art and may include photolithographic processes using a photoresist mask (not shown), sputter depositing an electrically conductive seed layer and electro-plating the shaping layer 502. The shaping layer 502 can be constructed of for example NiFe.

10 A first layer of magnetic write pole material 506 can then be deposited, such as by electroplating. This layer of write pole material is preferably a very high saturation, low coercivity material, and is preferably formed of laminated layers of a high magnetic saturation material (high Bsat) such as CoFe, NiFe or their alloys with interspersed non-magnetic film such as Cr, Ru, etc. A second layer of write pole material 508 is then  
15 deposited on top of the first layer 506. This second layer 508 may be a magnetic material that is more readily removed by reactive ion etching than the first layer 506.

Thereafter a layer of Ta may be deposited, followed by a mask 512, such as photoresist. As illustrated in Fig. 5, the mask 512 has a front edge that terminates at a desired taper stop point and extends backward therefrom.

20 With reference now to Fig. 6, a REI process may be performed to remove portions of the Ta layer 510 and 508. Preferably the REI process is performed at an angle as shown, so that the shadowing effect of the mask will promote a tapered removal of material also as shown. Since as mentioned above, the first magnetic pole layer 506 is

constructed of a material that is not as readily removed by RIE, the surface will tend flatten out when that surface is reached and at that point the RIE process should be stopped.

With reference now to Fig. 7, the mask 512 can be removed and successive thin  
5 layers of write gap material 702, and diamond like carbon (DLC) 704 deposited. The write gap material can be several non-magnetic materials and is preferably alumina. The write gap 702, and DLC 704 can be deposited by sputter deposition. Thereafter a relatively thicker layer of magnetic shield material 706 such as NiFe is deposited by processes such as seed layer sputtering, and electroplating. A chemical mechanical  
10 polishing process CMP 708 can then be performed, using the DLC layer 704 as a CMP stop so that the CMP process 708 stops at a desired level 710.

With reference to Fig. 8, a return pole 230 can then be constructed of a magnetic material such as NiFe. Although not visible in Fig. 8, the return pole 230 is laterally much wider than the shield 202 or the write pole tip 218.

15 With reference to Fig. 9 and 10, an embodiment of the tapered shield 902 can include laterally extending flares or wings 904. Such flares 904 can be beneficial in reducing side writing which might otherwise interfere with adjacent tracks of data on the magnetic medium 112 (Fig. 1). Such laterally extending flares, or wings 904 would preferably be disposed in front of the taper line 906 (ie. closer to the ABS), for optimal  
20 performance.

While various embodiments have been described above, it should be understood that they have been presented by way of example only, and not limitation. Other variation and embodiments falling within the scope of the invention will, no doubt be

apparent to those skilled in the art. For example, while the present invention was described with reference to a writer having a Return pole formed above the write pole (ie. trailing), the present invention could also be practiced on a perpendicular write element having a return pole below (ie. leading) the write pole. Thus, the breadth and scope of a preferred embodiment should not be limited by any of the above-described exemplary  
5 embodiments, but should be defined only in accordance with the following claims and their equivalents.